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(54) DISCHARGE LAMP DRIVING DEVICE, LIGHT SOURCE DEVICE, PROJECTOR, AND DISCHARGE LAMP DRIVING METHOD

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(51) **Int. Cl.**

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H04N 9/31	(2006.01)
G03B 21/00	(2006.01)
H05B 41/288	(2006.01)

(52) **U.S. Cl.**

CPC ***H04N 9/312*** (2013.01); ***G03B 21/005*** (2013.01); ***H05B 41/2883*** (2013.01); ***H05B 41/3928*** (2013.01)

(58) **Field of Classification Search**

CPC H05B 41/2883; H05B 41/3928; H05B 41/2928; H05B 41/36; G03B 21/2026; G03B 21/005; G03B 21/2053

USPC ...... 315/209 R, 224, 246, 287, 291, 307, 308

See application file for complete search history.

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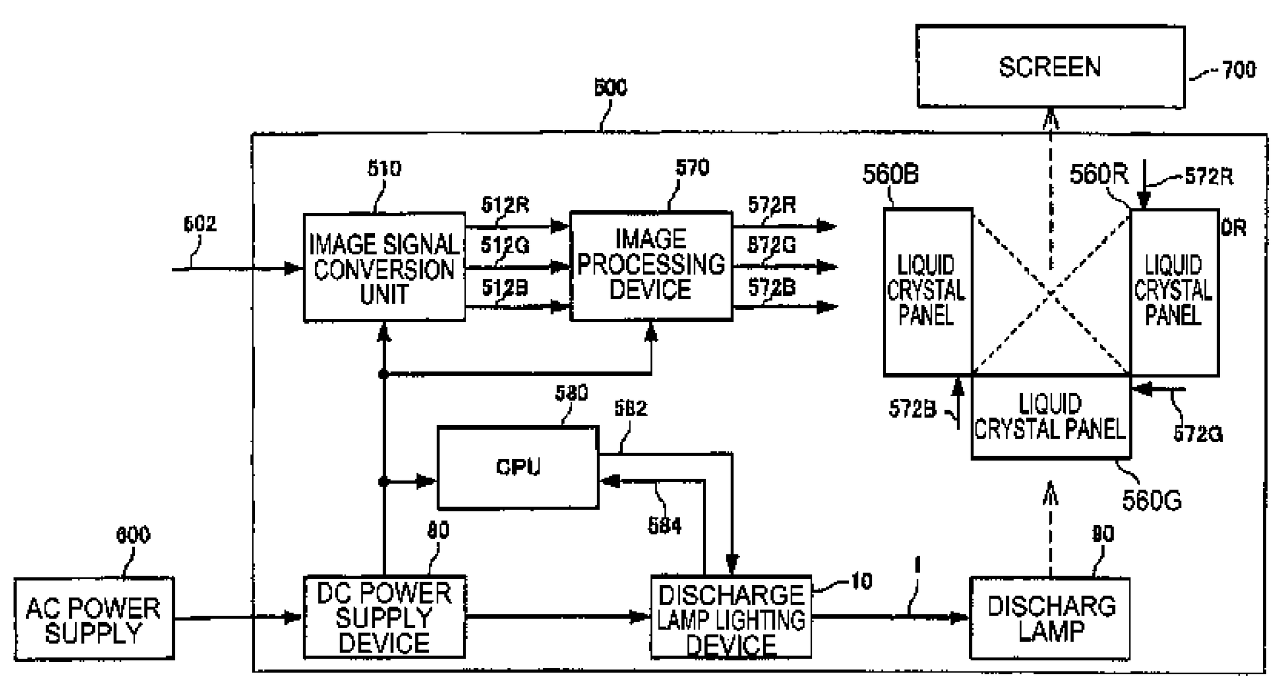
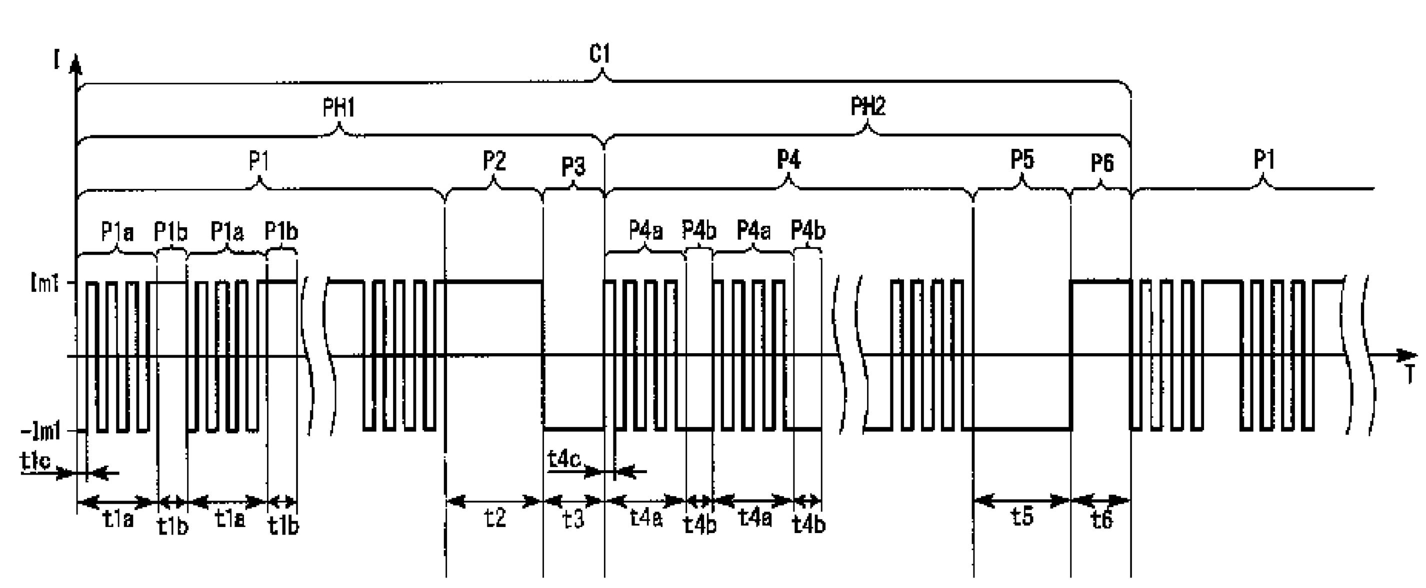
(57) **ABSTRACT**

A discharge lamp driving device includes: a discharge lamp driving unit that supplies a driving current to the discharge lamp; and a control unit that controls the discharge lamp driving unit. The driving current having driving periods is supplied, the driving period including: a mixing period which alternately has an AC period in which an alternating current is supplied and a first DC period in which a direct current is supplied, a second DC period which is provided immediately after the mixing period and in which a direct current having a polarity which is the same as that of the direct current in the first DC period is supplied, and a third DC period which is provided immediately after the second DC period and in which a direct current having a polarity opposite to that of the direct current in the second DC period is supplied.

18 Claims, 6 Drawing Sheets





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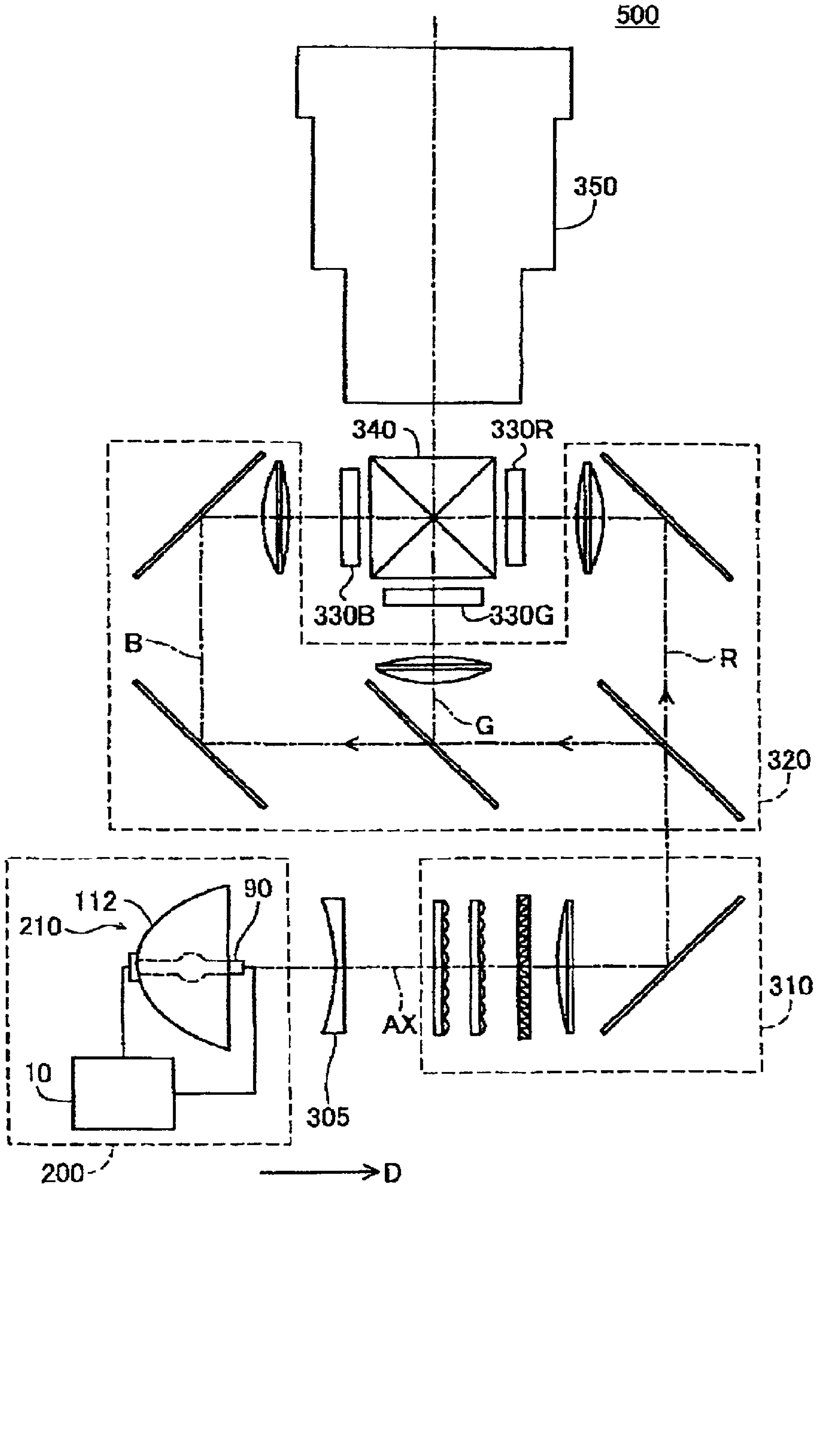


FIG. 1

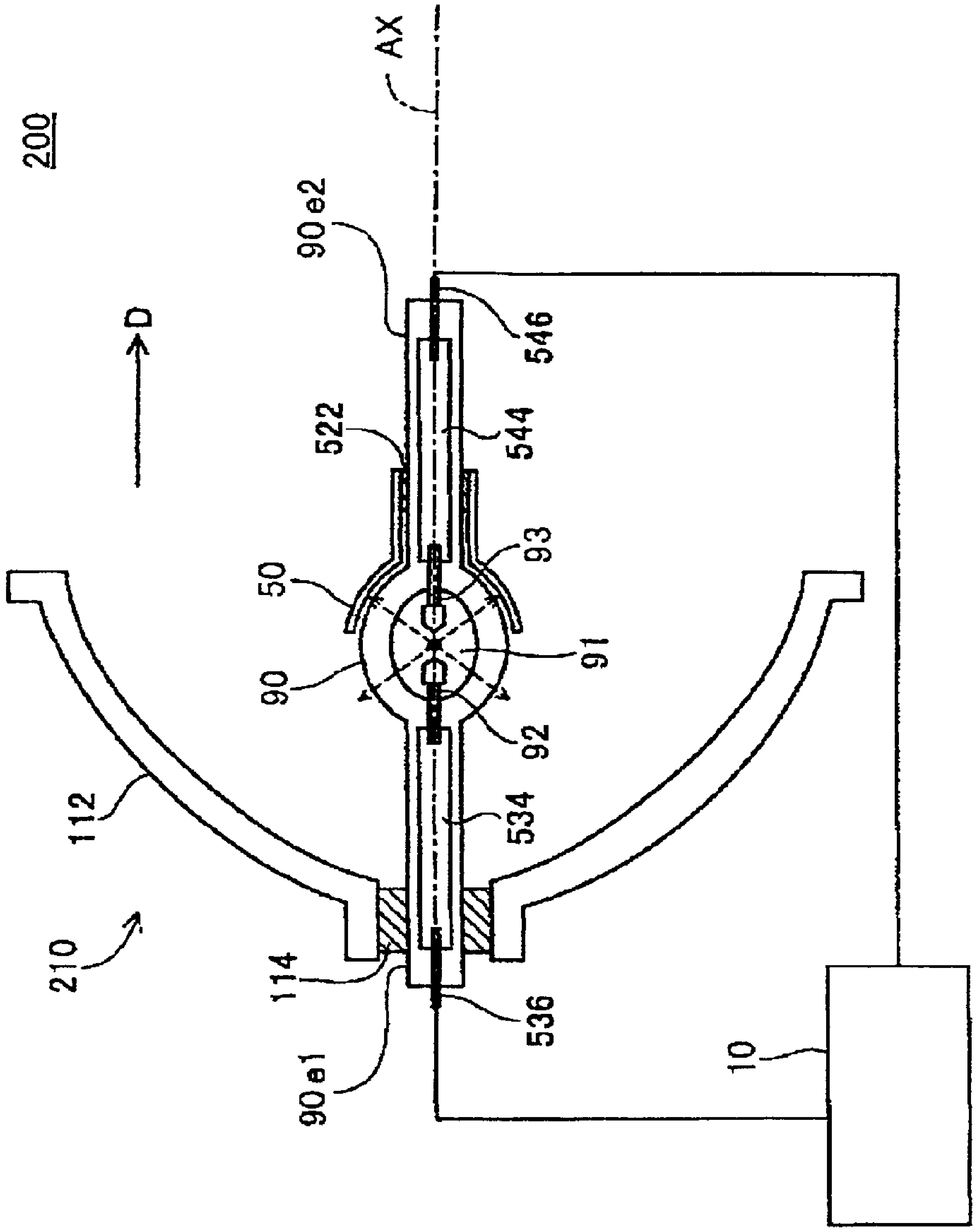

200
210
112
114
90e1
536
534
90
92
91
50
93
522
544
546
90e2
D
AX
10

FIG. 2

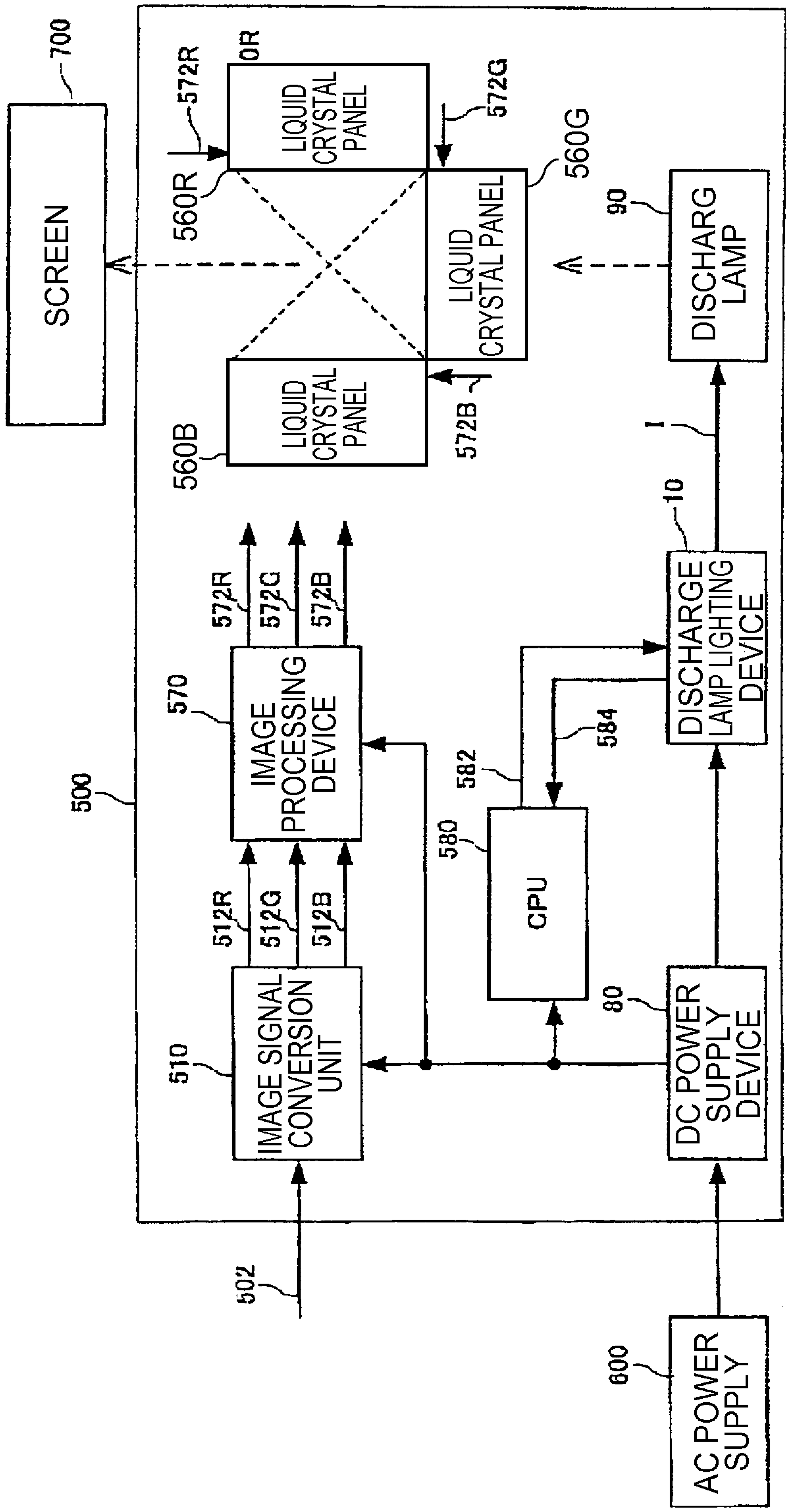
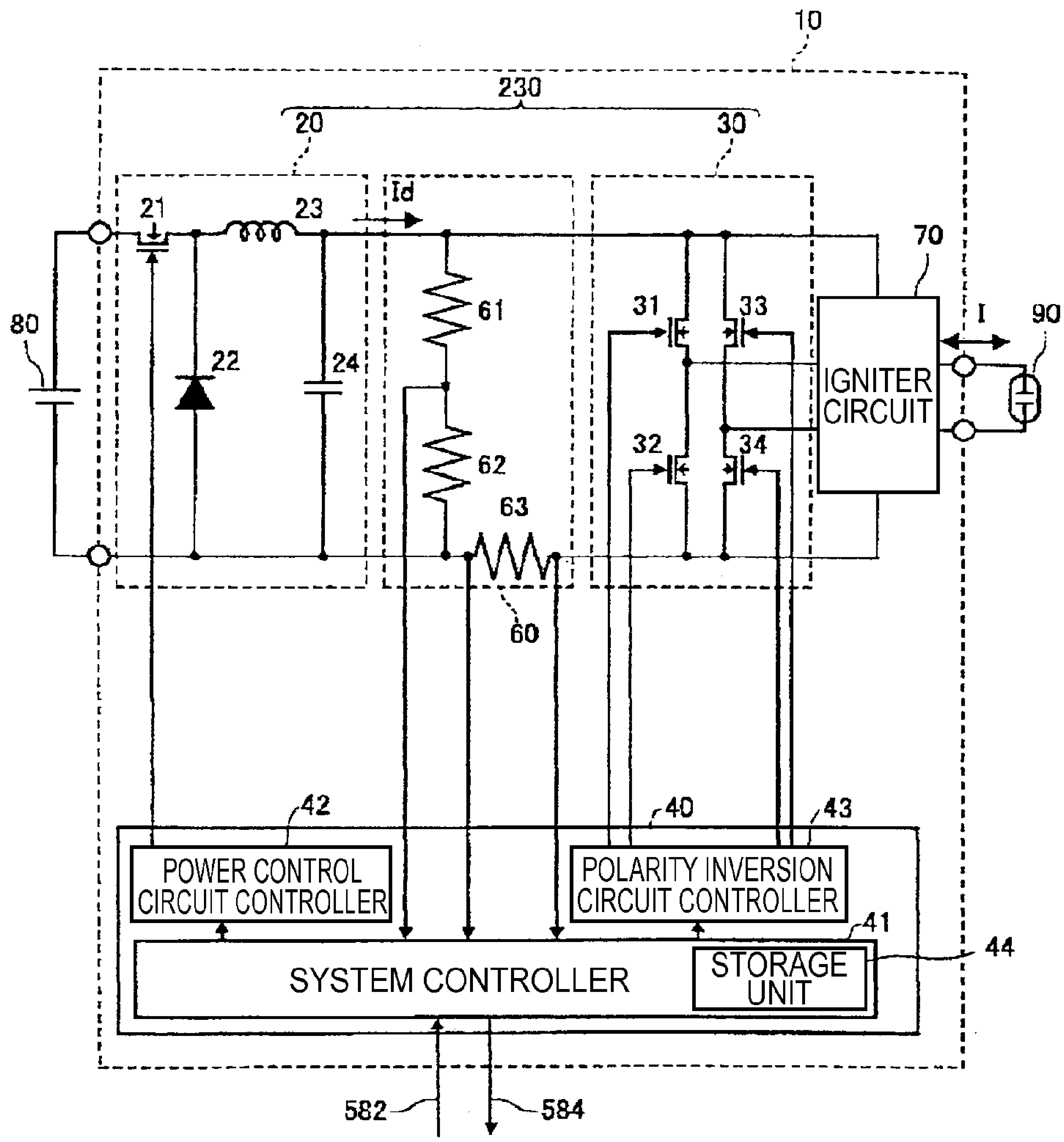
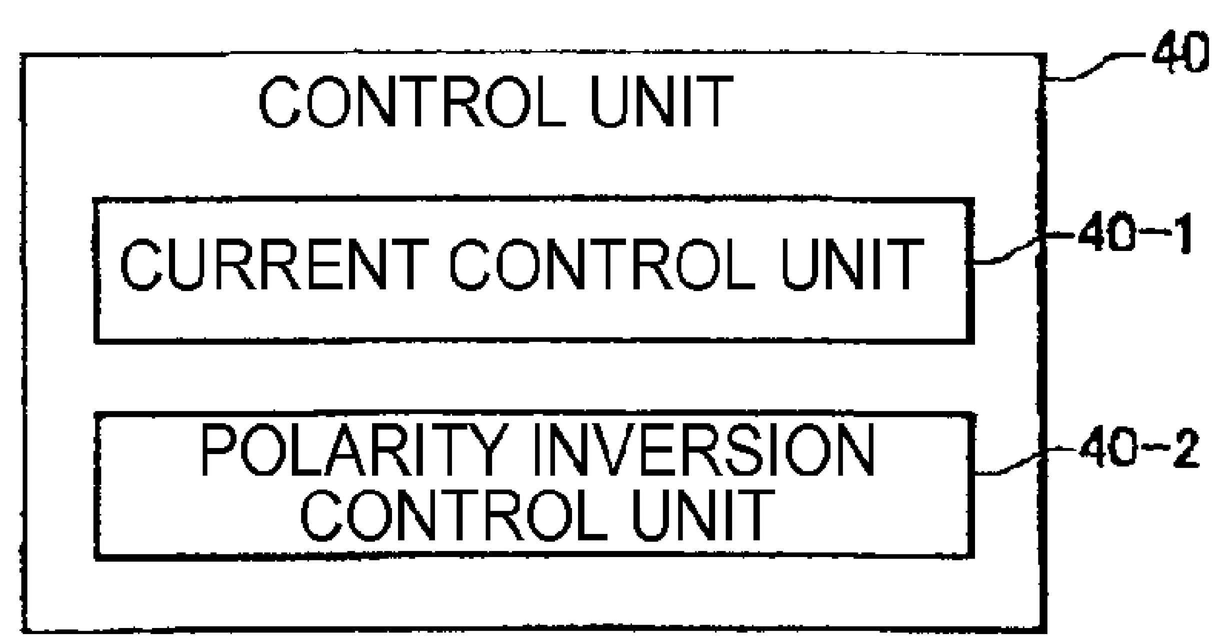

SCREEN
700
500
LIQUID CRYSTAL PANEL
560R
572R
572G
560G
LIQUID CRYSTAL PANEL
560B
572B
LIQUID CRYSTAL PANEL
DISCHARG LAMP
90
I
IMAGE PROCESSING DEVICE
570
572R
572G
572B
DISCHARGE LAMP LIGHTING DEVICE
10
584
582
CPU
580
IMAGE SIGNAL CONVERSION UNIT
510
512R
512G
512B
DC POWER SUPPLY DEVICE
80
502
AC POWER SUPPLY
600

FIG. 3



10
230
20
30
Id
21
23
70
80
61
31
33
I
90
22
24
IGNITER CIRCUIT
32
34
62
63
60
42
40
43
POWER CONTROL CIRCUIT CONTROLLER
POLARITY INVERSION CIRCUIT CONTROLLER
41
44
SYSTEM CONTROLLER
STORAGE UNIT
582
584

FIG. 4



CONTROL UNIT
40
CURRENT CONTROL UNIT
40-1
POLARITY INVERSION CONTROL UNIT
40-2

FIG. 5

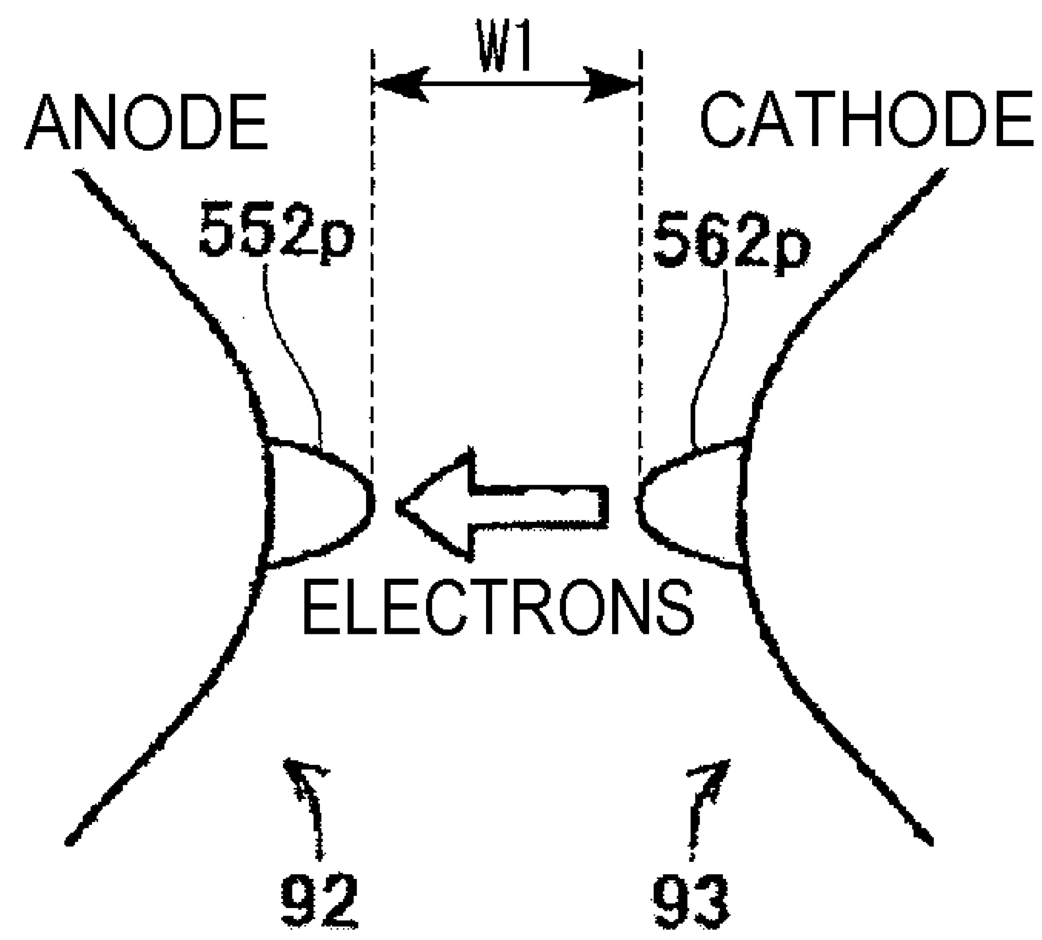

W1
ANODE
CATHODE
552p
562p
ELECTRONS
92
93

FIG. 6A

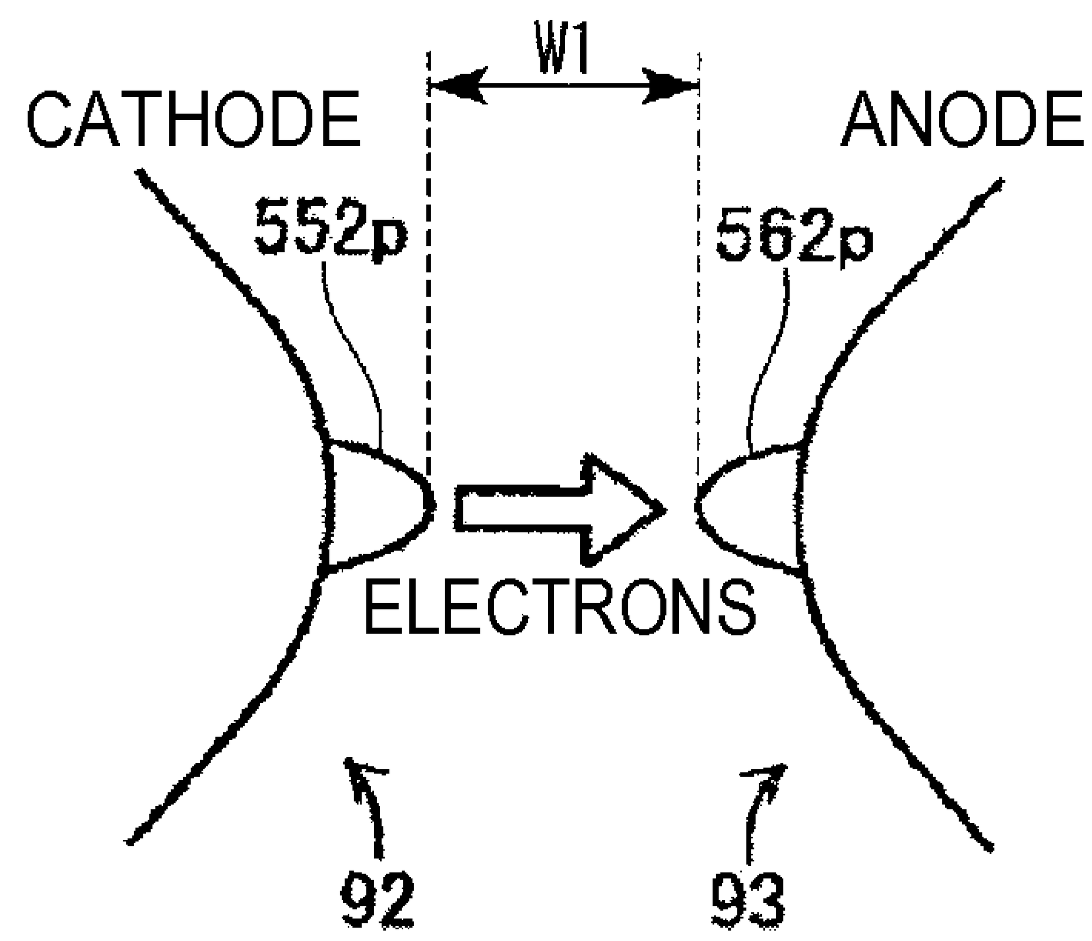
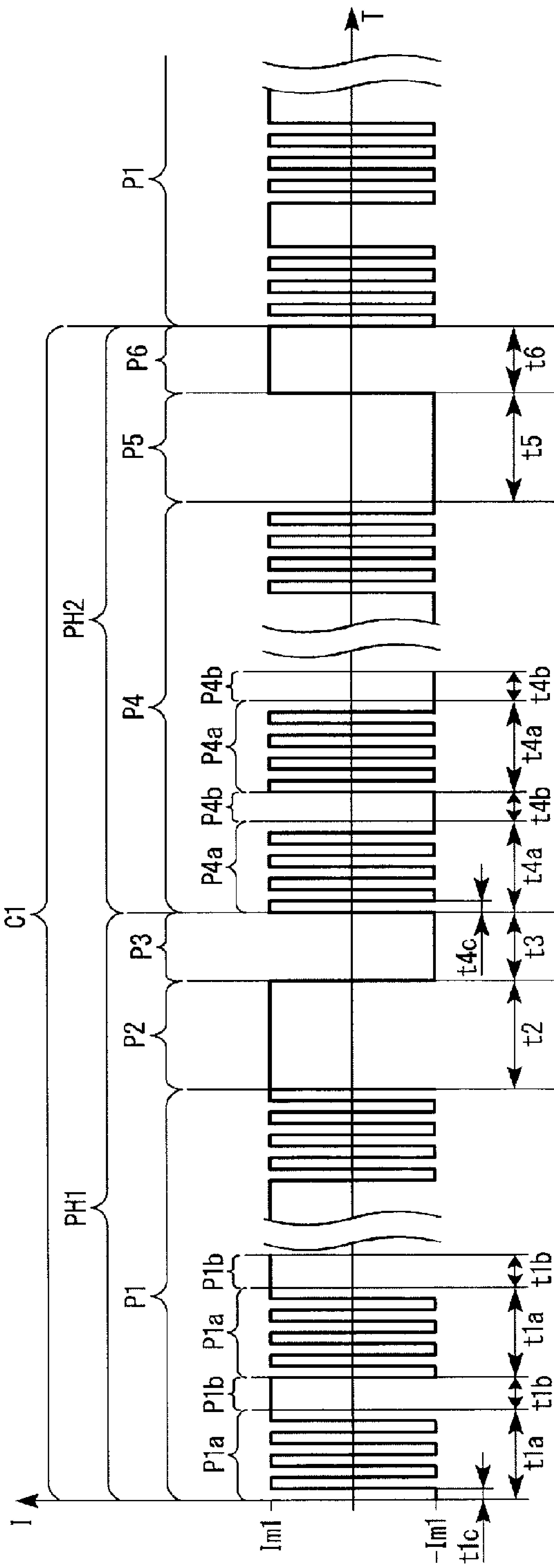
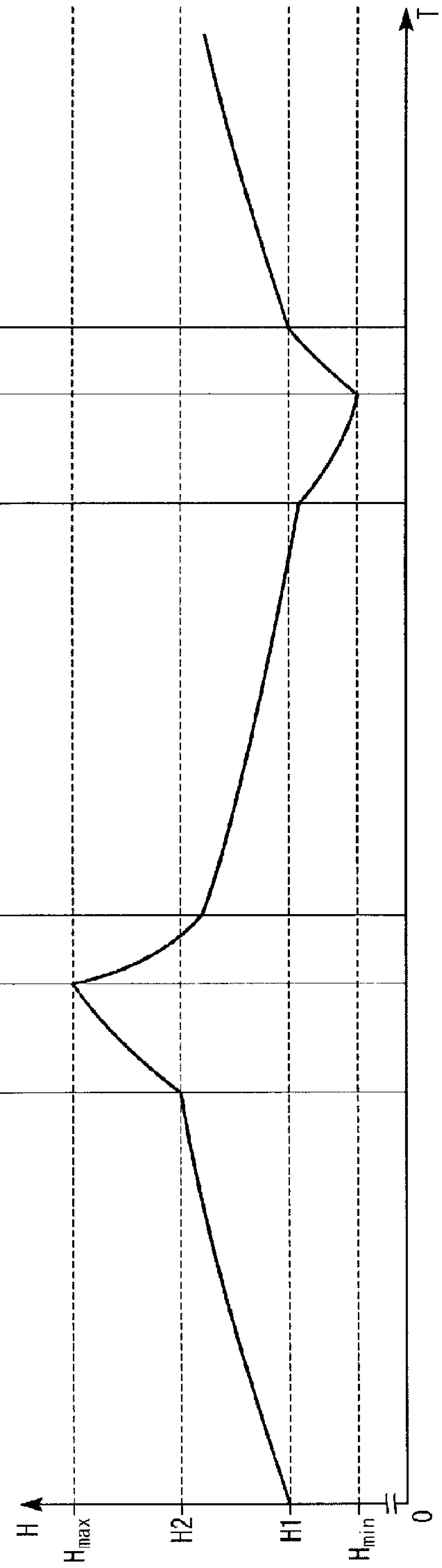

W1
CATHODE
ANODE
552p
562p
ELECTRONS
92
93

FIG. 6B



I
T
Im1
-Im1
C1
PH1
PH2
P1
P1a
P1b
P2
P3
P4
P4a
P4b
P5
P6
t1a
t1b
t1c
t2
t3
t4a
t4b
t4c
t5
t6

FIG. 7A



H
T
H_{max}
H2
H1
H_{min}
0

FIG. 7B

DISCHARGE LAMP DRIVING DEVICE, LIGHT SOURCE DEVICE, PROJECTOR, AND DISCHARGE LAMP DRIVING METHOD

BACKGROUND

1. Technical Field

The present invention relates to a discharge lamp driving device, a light source device, a projector, and a discharge lamp driving method.

2. Related Art

It is known that melting and solidifying of an electrode is repeated by making the temperature of an electrode of a discharge lamp fluctuate, and growth of a projection, which is a starting point of discharge, formed on a tip of the electrode can be controlled.

As a method of controlling the growth of such a projection, a method of driving a discharge lamp alternately supplying the direct current and the alternating current to a discharge lamp has been proposed (For example, JP-A-2011-23154).

The growth of a projection on the tip of the electrode becomes easily controlled as the fluctuation in temperature of the electrode is made to be large. However, in the driving method described above, the growth of a projection on the tip of the electrode is unlikely to be appropriately controlled in some cases due to the reason that the fluctuation in temperature may not be made to be sufficiently large. Accordingly, in the driving method described above, the growth of a projection is suppressed and, as a result, a service life of a discharge lamp is shortened in some cases.

SUMMARY

An advantage of some aspects of the invention is to provide a discharge lamp driving device capable of making the temperature of an electrode fluctuate largely, a light source device using such a discharge lamp driving device, a projector using such a light source device, and a method of driving a discharge lamp capable of making the temperature of an electrode fluctuate largely.

An aspect of the invention is directed to a discharge lamp driving device including: a discharge lamp driving unit that supplies a driving current for driving a discharge lamp to the discharge lamp; and a control unit that controls the discharge lamp driving unit, wherein the control unit controls the discharge lamp driving unit such that the driving current having driving periods is supplied to the discharge lamp, the driving period including: a mixing period which alternately has an AC period in which an alternating current is supplied to the discharge lamp and a first DC period in which a direct current is supplied to the discharge lamp, a second DC period which is provided immediately after the mixing period and in which a direct current having a polarity which is the same as that of the direct current in the first DC period is supplied to the discharge lamp, and a third DC period which is provided immediately after the second DC period and in which a direct current having a polarity opposite to that of the direct current in the second DC period is supplied to the discharge lamp, and the length of the second DC period is longer than the length of the first DC period and the length of the third DC period is longer than or equal to the length of the first DC period and shorter than the length of the second DC period.

According to the discharge lamp driving device of the aspect of the invention, the second DC period for which the direct current having a polarity which is the same as that of the direct current of the first DC period in the mixing period is supplied to the discharge lamp is provided immediately after the mixing period. Accordingly, the temperature of the electrode which is increased in the mixing period is further drastically increased in the second DC period. Further, the third DC period for which the direct current having a polarity opposite to that of the direct current in the second DC period is supplied to the discharge lamp is provided immediately after the second DC period. In this manner, the temperature of the electrode in the third DC period is drastically decreased. Therefore, according to the aspect of the discharge lamp driving device of the invention, since the third DC period for which the temperature of the electrode is drastically decreased is provided immediately after the second DC period for which the temperature of the electrode is drastically increased, the fluctuation in temperature of the electrode can be made large.

In the discharge lamp driving device, the driving current may have a plurality of the driving periods, and the direct currents in the first DC periods of the adjacent driving periods may have different polarities from each other.

According to this configuration, the fluctuation in temperature of both electrodes can be made large.

The length of the first DC period may be shorter than the length of the AC period, longer than the length of a half cycle of the alternating current in the AC period, and may be shorter than the length of the second DC period.

According to this configuration, while the electrode is heated during the mixing period, it is possible to prevent a projection on the tip portion of the electrode from being extremely melted.

The length of the first DC period may be equal to or greater than 0.5 ms and equal to or less than 7.0 ms.

According to this configuration, while the electrode is heated during the mixing period, it is possible to prevent a projection on the tip portion of the electrode from being extremely melted.

The length of the first DC period may be equal to or greater than 1.0 ms and equal to or less than 5.0 ms.

According to this configuration, it is possible to increase the temperature of the electrode more preferably in the mixing period.

The number of the first DC periods included in the mixing period may be equal to or greater than 5 and equal to or less than 50.

According to this configuration, it is possible to increase the temperature of the electrode more preferably in the mixing period.

A frequency of the alternating current in the AC period may be equal to or greater than 1 kHz.

According to this configuration, it is possible to prevent a fluctuation in temperature of the electrode in the AC period.

The length of the AC period may be equal to or greater than 1 cycle and equal to or less than 20 cycles.

According to this configuration, it is possible to prevent the temperature of the electrode from being drastically increased in the mixing period.

Another aspect of the invention is directed to a light source device including: a discharge lamp that emits light, and the discharge lamp driving device described above.

According to the light source device of the aspect of the invention, since the above-described discharge lamp driving device is included, a light source device capable of making the fluctuation in temperature of the electrode large can be obtained.

Still another aspect of the invention is directed to a projector including: the light source device described above; a light modulation element that modulates light emitted from the light source device according to a video signal; and a projection optical system that projects the light modulated by the light modulation element.

According to the projector of the aspect of the invention, since the above-described light source device is included, a projector with excellent reliability can be obtained.

Yet another aspect of the invention is directed to a method of driving a discharge lamp that is driven by supplying a driving current to the discharge lamp, the method including: supplying the driving current having driving periods to the discharge lamp, the driving period including: a mixing period which alternately has an AC period in which an alternating current is supplied to the discharge lamp and a first DC period in which a direct current is supplied to the discharge lamp, a second DC period which is provided immediately after the mixing period and in which a direct current having a polarity which is the same as that of the direct current in the first DC period is supplied to the discharge lamp, and a third DC period which is provided immediately after the second DC period and in which a direct current having a polarity opposite to that of the direct current in the second DC period is supplied to the discharge lamp, wherein the length of the second DC period is longer than the length of the first DC period, and the length of the third DC period is longer than or equal to the length of the first DC period and shorter than the length of the second DC period.

According to the method of driving a discharge lamp of the aspect of the invention, it is possible to make the fluctuation in temperature of the electrode large in the same manner as described above.

The driving current may have a plurality of the driving periods, and the direct currents in the first DC periods of the adjacent driving periods may have different polarities from each other.

According to the method with this configuration, the fluctuation in temperature of both electrodes can be made large.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention will be described with reference to the accompanying drawings, wherein like numbers reference like elements.

FIG. **1** is a view schematically illustrating a configuration of a projector according to the present embodiment.

FIG. **2** is a view illustrating a discharge lamp according to the present embodiment.

FIG. **3** is a block diagram illustrating various kinds of constituent elements of the projector according to the present embodiment.

FIG. **4** is a circuit diagram of a discharge lamp lighting device of the present embodiment.

FIG. **5** is a block diagram illustrating an example of a configuration of a control unit according to the present embodiment.

FIGS. **6**A and **6**B are views illustrating states of projections on tip ends of electrodes of the discharge lamp.

FIGS. **7**A and **7**B are diagrams illustrating an example of a driving current waveform of the discharge lamp according to the present embodiment.

DESCRIPTION OF EXEMPLARY EMBODIMENTS

Hereinafter, a projector according to an embodiment of the invention will be described with reference to the accompanying drawings.

Further, the range of the invention is not limited to the embodiments described below and can be arbitrarily changed within the range of the technical scope of the invention. In addition, for the sake of easy description of each configuration, in the drawings below, the scales or the numerical values of each structure may be different from those of the actual structure.

As illustrated in FIG. **1**, a projector **500** of the present embodiment includes a light source device **200**, a collimating lens **305**, an illumination optical system **310**, a color separation optical system **320**, three liquid crystal light valves (light modulation elements) **330**R, **330**G, and **330**B, a cross dichroic prism **340**, and a projection optical system **350**.

Light emitted from the light source device **200** passes through the collimating lens **305** and is incident on the illumination optical system **310**. The collimating lens **305** has a function of collimating light from the light source device **200**.

The illumination optical system **310** has a function of adjusting illumination of light emitted from the light source device **200** such that the illumination becomes uniform on the liquid crystal light valves **330**R, **330**G, and **330**B. The illumination optical system **310** has a function of aligning polarization directions of light emitted from the light source device **200** to one direction. The reason is that the light emitted from the light source device **200** is effectively used in the liquid crystal light valves **330**R, **330**G, and **330**B.

Light whose illuminance distribution and polarization direction are adjusted is incident to the color separation optical system **320**. The color separation optical system **320** separates the incident light into three colored light beams of red light (R), green light (G), and blue light (B). Three colored light beams are modulated by the liquid crystal light valves **330**R, **330**G, and **330**B in correspondence to respective colors. The liquid crystal light valves **330**R, **330**G, and **330**B include liquid crystal panels **560**R, **560**G, and **560**B, and polarizing plates (not illustrated) described below. The polarizing plates are arranged on respective light incident sides and light emitting sides of the liquid crystal panels **560**R, **560**G, and **560**B.

The modulated three colored light beams are synthesized by the cross dichroic prism **340**. The synthetic light is incident on the projection optical system **350**. The projection optical system **350** projects the incident light on a screen **700** (see FIG. **3**). In this manner, video is displayed on the screen **700**. Further, as each of the configurations of the collimating lens **305**, the illumination optical system **310**, the color separation optical system **320**, the cross dichroic prism **340**, and the projection optical system **350**, various known configurations can be employed.

FIG. **2** is a view illustrating the configuration of the light source device **200**. The light source device **200** includes a light source unit **210** and a discharge lamp lighting device (discharge lamp driving device) **10**. FIG. **2** is a cross-sectional view illustrating the light source unit **210**. The light source unit **210** includes a main reflecting mirror **112**, a discharge lamp **90**, and a sub-reflecting mirror **50**.

The discharge lamp lighting device **10** supplies a driving current (driving power) to the discharge lamp **90** and lights the discharge lamp **90**. The main reflecting mirror **112** reflects light discharged from the discharge lamp **90** toward an irradiation direction D. The irradiation direction D is parallel with an optical axis AX of the discharge lamp **90**.

The discharge lamp **90** has a rod shape extending along the irradiation direction D. One end portion (end portion on the left side of the figure) of the discharge lamp **90** is set as a first end portion **90**e**1** and another end portion (end portion on the right side of the figure) of the discharge lamp **90** is set as a second end portion **90**_e_**2**. As materials of the discharge lamp **90**, translucent materials such as quartz glass and the like are used. The middle portion of the discharge lamp **90** is swollen in a spherical shape and the inside thereof is a discharge space **91**. In the discharge space **91**, gas which is a discharge medium containing rare gas and a metal halogen compound is sealed.

Tips of a first electrode **92** and a second electrode **93** protrude in the discharge space **91**. The first electrode **92** is arranged on the first end portion **90**_e_**1** side of the discharge space **91**. The second electrode **93** is arranged on the second end portion **90**_e_**2** side of the discharge space **91**. The shape of the first electrode **92** and the second electrode **93** is a rod shape along the optical axis AX. The tip portions of the first electrode **92** and the second electrode **93** are arranged in the discharge space **91** such that the tip portions thereof are separated from each other by a predetermined distance and face each other. The materials of the first electrode **92** and the second electrode **93** are metals such as tungsten.

A first terminal **536** is provided on the first end portion **90**_e_**1** of the discharge lamp **90**. The first terminal **536** and the first electrode **92** are electrically connected by a conductive member **534** penetrating the inside of the discharge lamp **90**. In the same manner, a second terminal **546** is provided on the second end portion **90**_e_**2** of the discharge lamp **90**. The second terminal **546** and the second electrode **93** are electrically connected by a conductive member **544** penetrating the inside of the discharge lamp **90**. The materials of the first terminal **536** and the second terminal **546** are, for example, metals such as tungsten. As the materials of the conductive members **534** and **544**, molybdenum foil can be used.

The first terminal **536** and the second terminal **546** are connected to the discharge lamp lighting device **10**. The discharge lamp lighting device **10** supplies the driving current for driving the discharge lamp **90** to the first terminal **536** and the second terminal **546**. As a result, arc discharge occurs between the first electrode **92** and the second electrode **93**. The light (discharge light) generated due to the arc discharge is radiated toward all directions from a discharge position as indicated by a dashed arrow.

The main reflecting mirror **112** is fixed to the first end portion **90**_e_**1** of the discharge lamp **90** by a fixing member **114**. The main reflecting mirror **112** reflects light among discharge light, which travels toward the opposite side of the irradiation direction D, toward the irradiation direction D. The shape of the reflecting surface (surface on the discharge lamp **90** side) of the main reflecting mirror **112** is not particularly limited as long as discharge light can be reflected toward the irradiation direction D, and examples thereof include a spheroidal shape and a rotary parabolic shape. For example, in the case where the shape of the reflecting surface of the main reflecting mirror **112** is set as a rotary parabolic shape, the main reflecting mirror **112** can convert discharge light into light approximately parallel to the optical axis AX. In this manner, the collimating lens **305** can be omitted.

The sub-reflecting mirror **50** is fixed to the second end portion **90**_e_**2** side of the discharge lamp **90** by a fixing member **522**. The shape of the reflecting surface (surface of the discharge lamp **90** side) of the sub-reflecting mirror **50** is a spherical surface shape surrounding a portion of the second end portion **90**_e_**2** side of the discharge space **91**. The sub-reflecting mirror **50** reflects light among discharge light, which travels toward the opposite side of the side on which the main reflecting mirror **112** is arranged, toward the main reflecting mirror **112**. In this manner, utilization efficiency of light radiated from the discharge space **91** can be improved.

The materials of the fixing member **114** and **522** are not particularly limited as long as the materials are heat-resistant materials withstanding generation of heat from the discharge lamp **90**, and an inorganic adhesive can be exemplified. As a method of fixing the arrangement of the discharge lamp **90** with the main reflecting mirror **112** and the sub-reflecting mirror **50**, an arbitrary method can be employed without limiting a method of fixing the main reflecting mirror **112** and the sub-reflecting mirror **50** to the discharge lamp **90**. For example, the discharge lamp **90** and the main reflecting mirror **112** may be independently fixed to a housing (not illustrated) of the projector **500**. The same applies to the sub-reflecting mirror **50**.

Hereinafter, a circuit configuration of the projector **500** will be described.

FIG. **3** is a view illustrating an example of a circuit configuration of the projector **500** according to the present embodiment. The projector **500** includes an image signal conversion unit **510**, a DC power supply device **80**, the liquid crystal panels **560**R, **560**G, and **560**B, an image processing device **570**, and a central processing unit (CPU) **580** in addition to the optical system illustrated in FIG. **1**.

The image signal conversion unit **510** generates image signals **512**R, **512**G, and **512**B by converting an image signal **502** (a brightness-color difference signal or an analog RGB signal) input from the outside into a digital RGB signal having a predetermined word length and supplies the generated signals to the image processing device **570**.

The image processing device **570** performs image processing with respect to three image signals **512**R, **512**G, and **512**B respectively. The image processing device **570** supplies driving signals **572**R, **572**G, and **572**B for respectively driving the liquid crystal panels **560**R, **560**G, and **560**B to the liquid crystal panels **560**R, **560**G, and **560**B.

The DC power supply device **80** converts an AC voltage supplied from an external AC power supply **600** into a constant DC voltage. The DC power supply device **80** supplies the DC voltage to the image signal conversion unit **510** and the image processing device **570** positioned on the secondary side of a transformer (not illustrated and included in the DC power supply device **80**) and to the discharge lamp lighting device **10** positioned on the primary side of the transformer.

The discharge lamp lighting device **10** generates a high voltage between the electrodes of the discharge lamp **90** at startup and causes insulation breakdown to form a discharge path. Subsequently, the discharge lamp lighting device **10** supplies a driving current I for the discharge lamp **90** maintaining discharge.

The liquid crystal panels **560**R, **560**G, and **560**B are respectively included in the above-described liquid crystal light valves **330**R, **330**G, and **330**B. The liquid crystal panels **560**R, **560**_g_, and **560**B modulate transmittance (brightness) of colored light incident on respective liquid crystal panels **560**R, **560**G, and **560**B through the above-described optical system based on respective driving signals **572**R, **572**G, and **572**B.

The CPU **580** controls various operations from the start of lighting of the projector **500** to turning the light off. For example, in the example of FIG. **3**, a light-on instruction or a light-off instruction is output to the discharge lamp lighting device **10** through a communication signal **582**. The CPU **580** receives lighting information of the discharge lamp **90** through the communication signal **584** from the discharge lamp lighting device **10**.

Hereinafter, the configuration of the discharge lamp lighting device **10** will be described.

FIG. **4** is a view illustrating an example of a circuit configuration of the discharge lamp lighting device **10**.

The discharge lamp lighting device **10** includes a power control circuit **20**, a polarity inversion circuit **30**, a control unit **40**, an operation detecting unit **60**, and an igniter circuit **70** as illustrated in FIG. **4**.

The power control circuit **20** generates driving power supplied to the discharge lamp **90**. In the present embodiment, the power control circuit **20** is configured of a step down chopper circuit that inputs a voltage from the DC power supply device **80** and outputs a direct current Id by lowering the input voltage.

The power control circuit **20** includes a switch element **21**, a diode **22**, a coil **23**, and a capacitor **24**. The switch element **21** is configured of, for example, a transistor. In the present embodiment, one end of the switch element **21** is connected to a positive voltage side of the DC power supply device **80** and another end is connected to a cathode terminal of the diode **22** and one end of the coil **23**.

One end of the capacitor **24** is connected to the other end of the coil **23** and the other end of the capacitor **24** is connected to an anode terminal of the diode **22** and a negative voltage side of the DC power supply device **80**. A current control signal is input to a control terminal of the switch element **21** from the control unit **40** described below so that ON/OFF of the switch element **21** is controlled. As the current control signal, for example, a pulse width modulation (PWM) control signal may be used.

When the switch element **21** is turned ON, the current flows in the coil **23** and energy is stored in the coil **23**. Next, when the switch element **21** is turned OFF, the energy stored in the coil **23** is released through a path passing through the capacitor **24** and the diode **22**. As a result, a direct current Id is generated according to a ratio of an ON-time of the switch element **21**.

The polarity inversion circuit **30** inverts the polarity of the direct current Id input from the power control circuit **20** at a predetermined timing. In this manner, the polarity inversion circuit **30** generates a driving current I which is a direct current continuing for a controlled amount of time or a driving current I which is an alternating current having an arbitrary frequency and outputs the current. In the present embodiment, the polarity inversion circuit **30** is configured of an inverter bridge circuit (full-bridge circuit).

The polarity inversion circuit **30** includes a first switch element **31**, a second switch element **32**, a third switch element **33**, and a fourth switch element **34** configured of a transistor or the like. The polarity inversion circuit **30** has a configuration in which the first switch element **31** and the second switch element **32** connected in series to each other and the third switch element **33** and the fourth switch element **34** connected in series to each other are connected in parallel with each other. Polarity inversion control signals are respectively input to control terminals of the first switch element **31**, the second switch element **32**, the third switch element **33**, and the fourth switch element **34** from the control unit **40**. An ON/OFF operation of the first switch element **31**, the second switch element **32**, the third switch element **33**, and the fourth switch element **34** is controlled based on the polarity inversion control signals.

In the polarity inversion circuit **30**, an operation of alternately turning ON and OFF the first switch element **31** and the fourth switch element **34**, and the second switch element **32** and the third switch element **33** is repeatedly performed. In this manner, the polarity of the direct current Id output from the power control circuit **20** is alternately inverted. The polarity inversion circuit **30** generates a driving current I which is a direct current that maintains the same polarity state for a controlled amount of time or a driving current I that is an alternating current having a controlled frequency from a common connection point between the first switch element **31** and the second switch element **32** and a common connection point between the third switch element **33** and the fourth switch element **34** and outputs the current.

That is, the polarity inversion circuit **30** is controlled such that the second switch element **32** and the third switch element **33** are turned OFF when the first switch element **31** and the fourth switch element **34** are turned ON and the second switch element **32** and the third switch element **33** are turned ON when the first switch element **31** and the fourth switch element **34** are turned OFF. Accordingly, when the first switch element **31** and the fourth switch element **34** are turned ON, a driving current I flowing through one end of the capacitor **24**, the first switch element **31**, the discharge lamp **90**, and the fourth switch element **34** in order is generated. When the second switch element **32** and the third switch element **33** are turned ON, a driving current I flowing through one end of the capacitor **24**, the third switch element **33**, the discharge lamp **90**, and the second switch element **32** in order is generated.

In the present embodiment, a portion combining the power control circuit **20** and the polarity inversion circuit **30** corresponds to the discharge lamp driving unit **230**. That is, the discharge lamp driving unit **230** supplies the driving current I driving the discharge lamp **90** to the discharge lamp **90**.

The control unit **40** controls the discharge lamp driving unit **230**. In the example of FIG. **4**, the control unit **40** controls a retention time for which the driving current I maintains the same polarity, the current value of the driving current I, the frequency, and the like by controlling the power control circuit **20** and the polarity inversion circuit **30**. The details will be described below.

The control unit **40** performs polarity inversion control of controlling the retention time for which the driving current I maintains the same polarity, the frequency of the driving current I, and the like with respect to the polarity inversion circuit **30** at a polarity inversion timing of the driving current I. Further, the control unit **40** performs current control of controlling the current value of the direct current Id to be output with respect to the power control circuit **20**.

The configuration of the control unit **40** is not particularly limited. In the present embodiment, the control unit **40** includes a system controller **41**, a power control circuit controller **42**, and a polarity inversion circuit controller **43**. Further, a part or the entire control unit **40** may be configured of a semiconductor integrated circuit.

The system controller **41** controls the power control circuit **20** and the polarity inversion circuit **30** by controlling the power control circuit controller **42** and the polarity inversion circuit controller **43**. The system controller **41** may control the power control circuit controller **42** and the polarity inversion circuit controller **43** based on the lamp voltage detected by the operation detecting unit **60** and the driving current I.

In the present embodiment, the system controller **41** includes a storage unit **44**. The storage unit **44** may be provided independently from the system controller **41**.

The system controller **41** may control the power control circuit **20** and the polarity inversion circuit **30** based on information stored in the storage unit **44**. Further, information related to driving parameters such as the retention time for which the driving current I maintains the same polarity, the current value of the driving current I, the frequency, the waveform, and a modulation pattern may be stored in the storage unit **44**.

The power control circuit controller **42** controls the power control circuit **20** by outputting a current control signal to the power control circuit **20** based on the control signal from the system controller **41**.

The polarity inversion circuit controller **43** controls the polarity inversion circuit **30** by outputting a polarity inversion control signal to the polarity inversion circuit **30** based on the control signal from the system controller **41**.

The control unit **40** can perform the above-described control and various controls of processes described below by being realized using a dedicated circuit. The control unit **40** functions as a computer by the CPU executing control programs stored in the storage unit **44** and can perform various controls of these processes.

FIG. **5** is a view for describing another example of the configuration of the control unit **40**. As illustrated in FIG. **5**, the control unit **40** may be configured so as to function as a current control unit **40-1** that controls the power control circuit **20** and as a polarity inversion control unit **40-2** that controls the polarity inversion circuit **30** using control programs.

In the example illustrated in FIG. **4**, the control unit **40** is configured as a part of the discharge lamp lighting device **10**. Meanwhile, some of the functions of the control unit **40** may be carried out by the CPU **580**.

The operation detecting unit **60** may include a voltage detecting unit that detects the lamp voltage of the discharge lamp **90** and outputs driving voltage information to the control unit **40** and a current detecting unit that detects the driving current I and outputs driving current information to the control unit **40**. In the present embodiment, the operation detecting unit **60** includes a first resistor **61**, a second resistor **62**, and a third resistor **63**.

In the present embodiment, the voltage detecting unit detects the lamp voltage using a voltage divided by the first resistor **61** and the second resistor **62** which are connected in parallel with the discharge lamp **90** and connected to each other in series. Further, in the present embodiment, the current detecting unit detects the driving current I using a voltage generated in the third resistor **63** connected to the discharge lamp **90** in series.

The igniter circuit **70** is only operated at the start of lighting of the discharge lamp **90**. The igniter circuit **70** supplies a high voltage (a voltage higher than the voltage at normal lighting of the discharge lamp **90**) necessary for forming a discharge path by causing insulation breakdown between electrodes (between the first electrode **92** and the second electrode **93**) of the discharge lamp **90** at the start of lighting of the discharge lamp **90** to a portion between electrodes of the discharge lamp **90** (between the first electrode **92** and the second electrode **93**). In the present embodiment, the igniter circuit **70** is connected to the discharge lamp **90** in parallel.

Hereinafter, a relationship between the polarity of the driving current I and the temperature of the electrodes will be described.

FIGS. **6**A and **6**B are views illustrating an operation state of the first electrode **92** and the second electrode **93**.

FIGS. **6**A and **6**B illustrate tip portions of the first electrode **92** and the second electrode **93**. A projection **552**_p_ and a projection **562**_p_ are respectively formed on the tips of the first electrode **92** and the second electrode **93**. The discharge generated between the first electrode **92** and the second electrode **93** is mainly generated between the projection **552**_p_ and the projection **562**_p_.

FIG. **6**A illustrates a first polarity state in which the first electrode **92** is operated as an anode and the second electrode **93** is operated as a cathode. In the first polarity state, electrons are moved due to discharge from the second electrode **93** (cathode) to the first electrode **92** (anode). Electrons are released from the cathode (second electrode **93**). The electrons released from the cathode (second electrode **93**) collide with the tip of the anode (first electrode **92**). Due to this collision, heat is generated so that the temperature of the tip (projection **552**_p_) of the anode (first electrode **92**) is increased. Meanwhile, the temperature of the tip (projection **562**_p_) of the cathode (second electrode **93**) which is the side of releasing electrons is decreased.

FIG. **6**B illustrates a second polarity state in which the first electrode **92** is operated as the cathode and the second electrode **93** is operated as the anode. In the second polarity state, contrary to the first polarity state, electrons are moved from the first electrode **92** to the second electrode **93**. As a result, the temperature of the tip (projection **562**_p_) of the second electrode **93** is increased. Meanwhile, the temperature of the tip (projection **552**_p_) of the first electrode **92** is decreased.

As described above, the temperature of the anode with which electrons collide is increased and the temperature of the cathode releasing electrons is decreased. That is, in the first polarity state, the temperature of the first electrode **92** is increased and the temperature of the second electrode **93** is decreased. In the second polarity state, the temperature of the second electrode **93** is increased and the temperature of the first electrode **92** is decreased.

A distance **W1** between electrodes of the first electrode **92** and the second electrode **93** is the distance between the projection **552**_p_ and the projection **562**_p_. When the distance **W1** between electrodes is increased, the lamp voltage of the discharge lamp **90** is increased and the illuminance of the discharge lamp **90** is decreased during constant power driving. For this reason, by controlling the growth of the projection **552**_p_ and the projection **562**_p_ and maintaining the distance **W1** between electrodes, it is possible to suppress a decrease in illuminance of the discharge lamp **90** so that the service life of the discharge lamp **90** can be improved.

Next, control of the discharge lamp driving unit **230** performed by the control unit **40** will be described.

FIG. **7**A is a timing chart showing the driving current I to be supplied to the discharge lamp **90** in the present embodiment. The horizontal axis indicates a time T and the vertical axis indicates a current value of the driving current I. The driving current I indicates the current flowing in the discharge lamp **90**. The positive value indicates the first polarity state and the negative value indicates the second polarity state.

FIG. **7**B is a graph showing a change in temperature of the first electrode **92** corresponding to FIG. **7**A. The horizontal axis indicates the time T and the vertical axis indicates a temperature H of the first electrode **92**.

Further, since the temperatures of the first electrode **92** and the second electrode **93** are changed by drawing the same curve except that the changing timing of the first electrode is shifted from the changing timing of the second electrode, only the first electrode **92** is described as a typical example in some cases in the description below.

The control unit **40** controls the discharge lamp driving unit **230** such that the driving current I illustrated in FIG. **7**A is supplied to the discharge lamp **90**. That is, the control unit **40** controls the discharge lamp driving unit **230** such that a cycle **C1** is repeated.

The cycle **C1** alternately has a first driving period (driving period) **PH1** and a second driving period (driving period) **PH2** illustrated in FIG. **7**A. The first driving period **PH1** is a driving period for which the projection **552**P of the first electrode **92** is melted and the second driving period PH**2** is a driving period for which the projection **562***p* of the second electrode **93** is melted.

The first driving period PH**1** includes a mixing period P**1**, a second DC period P**2**, and a third DC period P**3**.

The mixing period P**1** is a period for which the temperature of the first electrode **92** is gradually increased. The mixing period P**1** is a period alternately having an AC period P**1***a* and a first DC period P**1***b*.

The AC period P**1***a* is a period for which the alternating current whose polarity is inverted between a current value Im**1** and a current value −Im**1** is supplied to the discharge lamp **90** as the driving current I. In the present embodiment, the alternating current in the AC period P**1***a* is a rectangular wave alternating current. The frequency of the alternating current of the AC period P**1***a* can be set to be 1 kHz or more. By setting the frequency of the alternating current in the AC period P**1***a* in this manner, a fluctuation in temperature H of the first electrode **92** in the AC period P**1***a* can be suppressed. The frequency of the alternating current in the AC period P**1***a* may be constant or modulated.

The number of AC periods P**1***a* included in the mixing period P**1** is, for example, in the range of 5 to 50, and a length t**1***a* of each AC period P**1***a* is in the range of 1 cycle to 20 cycles. By setting the number and the length thereof in this manner, it is possible to suppress a drastic increase in temperature H of the first electrode **92** in the mixing period P**1**.

The first DC period P**1***b* is a period for which the direct current of the current value Im**1** is supplied to the discharge lamp **90** as the driving current I. In the present embodiment, the direct current in the first DC period P**1***b* is a direct current having the first polarity whose current value is constant (Im**1**). The number of the first DC periods P**1***b* included in the mixing period P**1** is, for example, in the range of 5 to 50. By setting in this manner, it is possible to sufficiently increase the temperature H of the first electrode **92** in the mixing period P**1**.

In a case where the number of the first DC periods P**1***b* (AC periods P**1***a*) included in the mixing period P**1** is less than 5, it is difficult to sufficiently increase the temperature H of the first electrode **92**. In addition, in a case where the number of the first DC periods P**1***b* (AC periods P**1***a*) included in the mixing period P**1** is more than 50, there is a concern that the projection **552***p* is extremely melted or a fluctuation in brightness of the discharge lamp **90** is visually recognized and flickering occurs when the mixing period P**1** is switched to the second DC period P**2**.

A length t**1***b* of each first DC period P**1***b* is set such that the length t**1***b* is shorter than the length t**1***a* of the AC period P**1***a*, longer than a length t**1***c* of a half cycle of the AC period P**1***a*, shorter than a length t**2** of the second DC period P**2**, and in the range of 0.5 ms (millisecond) to 7.0 ms. Further, more preferably, the length t**1***b* of the first DC period P**1***b* is set to be in the range of 1 ms to 5.0 ms.

By setting the first DC period P**1***b* in this manner, the temperature H of the first electrode **92** is gradually increased in the mixing period P**1**.

The second DC period P**2** is provided immediately after the mixing period P**1** and immediately before the third DC period P**3**. That is, the second DC period P**2** is provided so as to be interposed between the mixing period P**1** and the third DC period P**3**.

The second DC period P**2** is a period for which the direct current of the current value Im**1** is supplied to the discharge lamp **90** as the driving current I. The polarity of the direct current in the second DC period P**2** is the same as that of the direct current in the first DC period P**1***b*. That is, the direct current in the second DC period P**2** is a direct current having the first polarity. In the present embodiment, the direct current in the second DC period P**2** has a constant current value (Im**1**).

The length t**2** of the second DC period P**2** is longer than the length t**1***b* of the first DC period P**1***b* in the mixing period P**1**. The length t**2** of the second DC period P**2** is, for example, in the range of 3 ms to 15 ms. By setting the length in this manner, the temperature H of the first electrode **92** can be preferably increased.

The third DC period P**3** is provided immediately after the second DC period P**2** and immediately before the mixing period P**4** in the second driving period PH**2** described below. That is, the third DC period P**3** is provided so as to be interposed between the second DC period P**2** and the mixing period P**4**.

The third DC period P**3** is a period for which the direct current whose current value is −Im**1** is supplied to the discharge lamp **90** as the driving current I. The polarity of the direct current in the third DC period P**3** is opposite to that of the direct current in the second DC period P**2**. That is, the direct current in the third DC period P**3** is a direct current having the second polarity. In the present embodiment, the direct current in the third DC period P**3** has a constant current value (−Im**1**).

A length t**3** of the third DC period P**3** is longer than or equal to the length t**1***b* of the first DC period P**1***b* in the mixing period P**1** and shorter than the length t**2** of the second DC period P**2**. The length t**3** of the third DC period P**3** is, for example, in the range of 1 ms to 10 ms. By setting the length in this manner, the temperature H of the first electrode **92** can be preferably decreased.

The second driving period PH**2** includes the mixing period P**4**, a second DC period P**5**, and a third DC period P**6**.

The mixing period P**4** is a period alternately having an AC period P**4***a* and a first DC period P**4***b*.

The AC period P**4***a* is a period for which the alternating current whose polarity is inverted between the current value Im**1** and the current value −Im**1** is supplied to the discharge lamp **90** as the driving current I. In the present embodiment, the alternating current in the AC period P**4***a* is a rectangular wave alternating current. The frequency of the alternating current of the AC period P**4***a* can be set to be 1 kHz or more in the same manner as that of the AC period P**1***a*. The frequency of the alternating current in the AC period P**4***a* may be constant or modulated.

The number of AC periods P**4***a* included in the mixing period P**4** is, for example, in the range of 5 to 50, and a length t**4***a* of each AC period P**4***a* is in the range of 1 cycle to 20 cycles in the same manner as that of the AC period P**1***a*.

The first DC period P**4***b* is a period for which the direct current having the current value −Im**1** is supplied to the discharge lamp **90** as the driving current I. The polarity of the direct current in the first DC period P**4***b* is opposite to that of the direct current in the first DC period P**1***b* of the first driving period PH**1**. That is, the direct current in the first DC period P**4***b* is a direct current having the second polarity. In other words, the direct currents in the first DC periods in the adjacent driving periods have different polarities from each other. In the present embodiment, the direct current in the first DC period P**4***b* has a constant current value (−Im**1**).

The number of the AC periods P**4***a* included in the mixing period P**4** is, for example, in the range of 5 to 50 in the same manner as that of the AC period P**1***a*.

A length t**4***b* of each first DC period P**4***b* is set such that the length t**4***b* is shorter than the length t**4***a* of the AC period P**4***a*, longer than a length t**4***c* of a half cycle of the AC period P**4***a*, shorter than a length t**5** of the second DC period P**5**, and in the range of 0.5 ms (millisecond) to 7.0 ms. Further, more preferably, the length t**4**b of the first DC period P**4**b is set to be in the range of 1 ms to 5.0 ms.

By setting the first DC period P**4**b in this manner, the temperature H of the second electrode **93** is gradually increased in the mixing period P**4**.

The second DC period P**5** is provided immediately after the mixing period P**4** and immediately before the third DC period P**6**. That is, the second DC period P**5** is provided so as to be interposed between the mixing period P**4** and the third DC period P**6**.

The second DC period P**5** is a period for which the direct current having the current value −Im**1** is supplied to the discharge lamp **90** as the driving current I. The polarity of the direct current in the second DC period P**5** is the same as that of the direct current in the first DC period P**4**b. That is, the direct current in the second DC period P**5** is a direct current having the second polarity. The polarity of the direct current in the second DC period P**5** is opposite to that of the direct current in the second DC period P**2** of the first driving period PH**1**. In other words, the direct currents in the second DC periods in the adjacent driving periods have different polarities from each other. In the present embodiment, the direct current in the second DC period P**5** has a constant current value (−Im**1**).

The length t**5** of the second DC period P**5** is, for example, in the range of 3 ms to 15 ms in the same manner as that of the second DC period P**2**.

The third DC period P**6** is provided immediately after the second DC period P**5** and immediately before the mixing period P**1** in the first driving period PH**1**. That is, the third DC period P**6** is provided so as to be interposed between the second DC period P**5** and the mixing period P**1**.

The third DC period P**6** is a period for which the direct current having the current value Im**1** is supplied to the discharge lamp **90** as the driving current I. The polarity of the direct current in the third DC period P**6** is opposite to that of the direct current in the second DC period P**5**. That is, the direct current in the third DC period P**6** is a direct current having the first polarity. The polarity of the direct current in the third DC period P**6** is opposite to that of the direct current in the third DC period P**3** of the first driving period PH**1**. In other words, the direct currents in the third DC periods in the adjacent driving periods have different polarities from each other. In the present embodiment, the direct current in the third DC period P**6** has a constant current value (Im**1**).

A length t**6** of the third DC period P**6** is longer than or equal to the length t**4**b of the first DC period P**4**b in the mixing period P**4** and shorter than the length t**5** of the second DC period P**5** in the same manner as that of the third DC period P**3**. The length t**6** of the third DC period P**6** is, for example, in the range of 1 ms to 10 ms.

The frequencies of the alternating currents in the AC periods P**1**a and P**4**a may be the same as or different from each other.

The numbers included in the lengths t**1**a and t**4**a and the mixing periods P**1** and P**4** of the AC periods P**1**a and P**4**a may be the same as or different from each other.

The numbers included in the lengths t**1**b and t**4**b and the mixing periods P**1** and P**4** of the first DC periods P**1**b and P**4**b may be the same as or different from each other.

The number of the AC periods Pal and P**4**a included in the mixing periods P**1** and P**4** may be the same as or different from the number of the first DC periods P**1**b and P**4**b included in the mixing periods P**1** and P**4**.

The lengths t**2** and t**5** of the second DC periods P**2** and P**5** may be the same as or different from each other.

The lengths t**3** and t**6** of the third DC periods P**3** and P**6** may be the same as or different from each other.

Next, an increase in temperature of the first electrode **92** when the driving current I of the present embodiment is supplied to the discharge lamp **90** will be described.

First, in the mixing period P**1** of the first driving period PH**1**, the temperature H of the first electrode **92** is gradually increased from H**1** to H**2** as illustrated in FIG. **7**B because the direct current in the first DC period P**1**b has the first polarity.

Here, since the first polarity and the second polarity are alternately exchanged in the AC period P**1**a of the mixing period P**1**, the temperature H of both electrodes is easily held to be constant. As the frequency of the alternating current of the AC period P**1**a is increased, the temperature H of both electrodes is easily held to be constant. Specifically, as described above, it is preferable that the frequency of the AC period P**1**a is 1 kHz or more.

Next, in the second DC period P**2**, since the direct current having the same polarity as that of the direct current in the first DC period P**1**b of the mixing period P**1** is supplied to the discharge lamp **90**, the temperature H of the first electrode **92** is drastically increased and becomes Hmax.

Next, in the third DC period P**3**, since the direct current having the polarity (second polarity) opposite to that of the direct current in the second DC period P**2** is supplied to the discharge lamp **90**, the temperature H of the first electrode **92** is drastically decreased.

Next, in the mixing period P**4** of the second driving period PH**2**, since the polarity of the direct current in the first DC period P**4**b is the second polarity, the temperature H of the first electrode **92** is gradually decreased.

Next, even in the second DC period P**5**, since the direct current of the second polarity is supplied to the discharge lamp **90**, the temperature H of the first electrode **92** is drastically decreased and becomes Hmin.

Next, in the third DC period P**6**, since the polarity of the direct current is the first polarity, the temperature H of the first electrode **92** is drastically increased and becomes H**1** from Hmin.

Moreover, in the mixing period P**1** of the first driving period PH**1** again, the temperature H of the first electrode **92** is gradually increased and the same temperature change is repeated hereinafter.

The change in temperature H of the second electrode **93** is symmetrical with the change in temperature H of the first electrode **92**. Specifically, the temperature H of the second electrode **93** is changed in the same manner as that of the temperature H of the first electrode **92** in the second driving period PH**2** illustrated in FIG. **7**B in the first driving period PH**1** and is changed in the same manner as that of the temperature H of the first electrode **92** in the first driving period PH**1** illustrated in FIG. **7**B in the second driving period PH**2**.

As described above, the control unit **40** of the present embodiment controls the discharge lamp driving unit **230** such that the current is supplied to the discharge lamp **90** according to respective periods described above.

Controlling of the discharge lamp driving unit **230** performed by the control unit **40** can be expressed as a discharge lamp driving method. That is, the method of driving a discharge lamp of the present embodiment is a method of supplying the driving current I to the discharge lamp **90** to be driven, and the driving current includes the first driving period PH**1** and the second driving period PH**2** having the mixing periods P**1** and P**4** which alternately have AC periods P**1**a and P**4**a for which the alternating current is supplied to the discharge lamp **90** and first DC periods P**1***b* and P**4***b* for which the direct current is supplied to the discharge lamp **90**, second DC periods P**2** and P**5** which are provided immediately after the mixing periods P**1** and P**4** and for which the direct current having a polarity which is the same as that of the direct current in the first DC periods P**1***b* and P**4***b* is supplied to the discharge lamp **90**, and third DC periods P**3** and P**6** which are provided immediately after the second DC periods P**2** and P**5** and for which the direct current having a polarity opposite to that of the direct current in the second DC periods P**2** and P**5** is supplied to the discharge lamp **90**, and the length of the second DC periods P**2** and P**5** is longer than the length of the first DC periods P**1***b* and P**4***b*, and the length of the third DC periods P**3** and P**6** is longer than or equal to the length of the first DC periods P**1***b* and P**4***b* and shorter than the length of the second DC periods P**2** and P**5**.

According to the present embodiment, the discharge lamp driving unit **230** is controlled such that the second DC period P**2** is provided immediately after the mixing period P**1** and the third DC period P**3** is provided immediately after the second DC period P**2**. Since the second DC period P**2** has the same polarity as that of the first DC period P**1***b* in the mixing period P**1**, the temperature H of the first electrode **92** is drastically increased in the second DC period P**2**. Further, since the third DC period P**3** has the polarity opposite to that of the first DC period P**1***b* in the mixing period P**1**, the temperature H of the first electrode **92** is drastically decreased in the third DC period P**3**. In this manner, according to the present embodiment, the fluctuation in temperature H of the first electrode **92** can be made large in the third DC period P**3**.

The growth of projections on tips of the electrodes is controlled by repeating melting and solidifying of the electrodes. At this time, when the fluctuation in temperature added to the electrodes is small, the shape of the projections is unlikely to be controlled.

Meanwhile, according to the present embodiment, since the fluctuation in temperature added to the first electrode **92** can be made large in the manner described above, growth of the projection **552***p* of the first electrode **92** can be easily controlled. Therefore, according to the present embodiment, the service life of the discharge lamp can be improved.

In addition, since the value of the current supplied to the discharge lamp is small at the time of a low-power mode (eco-mode) or when the discharge lamp is deteriorated, it is difficult to increase the temperature of the electrodes and to allow the projections of the electrodes to grow. On the contrary, according to the present embodiment, since the fluctuation in temperature added to the first electrode **92** can be made large, the growth of the projection **552***p* of the first electrode **92** is easily controlled at the time of the low-power mode or when the discharge lamp is deteriorated. That is, the effect is particularly significant at the time of the low-power mode or when the discharge lamp is deteriorated in the present embodiment.

In addition, according to the present embodiment, the length t**1***b* of the first DC period P**1***b* is set to be smaller than the length t**1***a* of the AC period P**1***a*, larger than the length t**1***c* of a half cycle of the AC period P**1***a*, smaller than the length t**2** of the second DC period P**2**, and in the range of 0.5 ms to 7.0 ms. In this manner, it is possible to prevent the first electrode **92** from being extremely melted and to increase the temperature of the first electrode **92**. Hereinafter, the details will be described.

In the mixing period alternately having the alternating current and the direct current, when the length of a period for which the direct current is supplied is large, the temperature of the electrodes is rapidly increased and only the projections of the electrodes are extremely melted in some cases. In such a case, there is a concern that the growth of the projections is difficult, the electrodes are consumed, and thus, the service life of the discharge lamp is shortened when the projections melted due to a decrease in temperature of the electrodes are solidified again.

Meanwhile, according to the present embodiment, it is possible to suppress a drastic increase in the temperature H of the first electrode **92** by setting the length t**1***b* of the first DC period P**1***b* in the mixing period P**1** in the above-described manner. It is considered that the reason is based on the following principle.

In the present embodiment, since the length t**1***b* of the first DC period P**1***b* is sufficiently small, the increased width of the temperature H of the first electrode **92** in the first DC period P**1***b* is small. In this manner, it is possible to prevent the projection **552***p* from being extremely melted.

In addition, in the AC period P**1***a*, the temperature H of the first electrode **92** is maintained and the temperature H of the first electrode **92** is increased again due to the first DC period P**1***b*. In the present embodiment, since the length t**1***a* of the AC period P**1***a* is set to be longer than the length t**1***b* of the first DC period P**1***b*, a temperature gradient with respect to the time T of the first electrode **92** becomes gentle.

Further, in the case where the length t**1***b* of the first DC period P**1***b* is shorter than the length t**1***c* of a half cycle of the AC period P**1***a*, it is considered that the temperature H of the first electrode **92** is not increased or is decreased because the AC period P**1***a* is largely affected compared to the first DC period P**1***b* in terms of an increase in temperature H of the first electrode **92**.

On the contrary, according to the present embodiment, since the length t**1***b* of the first DC period P**1***b* is longer than the length t**1***c* of a half cycle of the AC period P**1***a*, the temperature H of the first electrode **92** can be increased in the mixing period P**1**.

As described above, according to the present embodiment, it is possible to prevent the projection **552***p* of the first electrode **92** from being extremely melted in the mixing period P**1** and to gradually increase the temperature H of the first electrode **92**.

Further, since the electrodes of the discharge lamp are deteriorated with time and the projections are easily melted, it is difficult to control the extreme melting of the projections and the growth of the projections. Meanwhile, in the present embodiment, since extreme melting of the projection **552***p* can be prevented, a significant effect can be obtained when the discharge lamp **90** is deteriorated with time.

Further, in the present embodiment, for example, the length of each period may be changed in response to deterioration of the discharge lamp **90** and switching a driving mode to the low-power mode. More specifically, in the present embodiment, the length t**2** of the second DC period P**2** and the length t**3** of the third DC period P**3** may be increased in response to deterioration of the discharge lamp **90**. By performing control in this manner, it is possible to allow the projection **552***p* of the first electrode **92** to grow appropriately according to a state in which the discharge lamp **90** is deteriorated. Further, in the present embodiment, the discharge lamp driving unit **230** may be controlled such that the length t**1***b* of the first DC period P**1***b* is decreased in response to the deterioration of the discharge lamp **90**. By performing control in this manner, it is possible to appropriately increase the temperature H of the first electrode **92** within the range in which the projection **552**P is not extremely melted in response to a change in ease of melting of the projection **552***p*.

Furthermore, in the embodiment described above, the length t**1***b* of each first DC period P**1***b* is set to be shorter than the length t**1***a* of the AC period P**1***a*, longer than the length t**1***c* of a half cycle of the AC period P**1***a*, shorter than the length t**2** of the second DC period P**2**, and in the range of 0.5 ms to 7.0 ms, but the length thereof is not limited thereto. In the present embodiment, for example, the length t**1***b* of the first DC period P**1***b* may be set to be longer than 7.0 ms.

The entire disclosure of Japanese Patent Application No. 2014-047295, filed Mar. 11, 2014 is expressly incorporated by reference herein.

What is claimed is:

1. A discharge lamp driving device comprising:

a discharge lamp driving unit that supplies a driving current for driving a discharge lamp to the discharge lamp; and

a control unit that controls the discharge lamp driving unit,

wherein the control unit controls the discharge lamp driving unit such that the driving current having driving periods is supplied to the discharge lamp, the driving period including:

a mixing period which alternately has an AC period in which an alternating current is supplied to the discharge lamp and a first DC period in which a direct current is supplied to the discharge lamp,

a second DC period which is provided immediately after the mixing period and in which a direct current having a polarity which is the same as that of the direct current in the first DC period is supplied to the discharge lamp, and

a third DC period which is provided immediately after the second DC period and in which a direct current having a polarity opposite to that of the direct current in the second DC period is supplied to the discharge lamp,

the length of the second DC period is longer than the length of the first DC period, and

the length of the third DC period is longer than or equal to the length of the first DC period and shorter than the length of the second DC period.

2. The discharge lamp driving device according to claim **1**,

wherein the driving current has a plurality of the driving periods, and

the direct currents in the first DC periods of the adjacent driving periods have different polarities from each other.

3. The discharge lamp driving device according to claim **1**, wherein the length of the first DC period is shorter than the length of the AC period, longer than the length of a half cycle of the alternating current in the AC period, and is shorter than the length of the second DC period.

4. The discharge lamp driving device according to claim **3**, wherein the length of the first DC period is equal to or greater than 0.5 ms and equal to or less than 7.0 ms.

5. The discharge lamp driving device according to claim **4**, wherein the length of the first DC period is equal to or greater than 1.0 ms and equal to or less than 5.0 ms.

6. The discharge lamp driving device according to claim **1**, wherein the number of the first DC periods included in the mixing period is equal to or greater than 5 and equal to or less than 50.

7. The discharge lamp driving device according to claim **1**, wherein a frequency of the alternating current in the AC period is equal to or greater than 1 kHz.

8. The discharge lamp driving device according to claim **1**, wherein the length of the AC period is equal to or greater than 1 cycle and equal to or less than 20 cycles.

9. A projector comprising:

a discharge lamp that emits light,

the discharge lamp driving device according to claim **1**;

a light modulation element that modulates light emitted from the discharge lamp according to a video signal; and

a projection optical system that projects the light modulated by the light modulation element.

10. A projector comprising:

a discharge lamp that emits light,

the discharge lamp driving device according to claim **2**;

a light modulation element that modulates light emitted from the discharge lamp according to a video signal; and

a projection optical system that projects the light modulated by the light modulation element.

11. A projector comprising:

a discharge lamp that emits light,

the discharge lamp driving device according to claim **3**;

a light modulation element that modulates light emitted from the discharge lamp according to a video signal; and

a projection optical system that projects the light modulated by the light modulation element.

12. A projector comprising:

a discharge lamp that emits light,

the discharge lamp driving device according to claim **4**;

a light modulation element that modulates light emitted from the discharge lamp according to a video signal; and

a projection optical system that projects the light modulated by the light modulation element.

13. A projector comprising:

a discharge lamp that emits light,

the discharge lamp driving device according to claim **5**;

a light modulation element that modulates light emitted from the discharge lamp according to a video signal; and

a projection optical system that projects the light modulated by the light modulation element.

14. A projector comprising:

a discharge lamp that emits light,

the discharge lamp driving device according to claim **6**;

a light modulation element that modulates light emitted from the discharge lamp according to a video signal; and

a projection optical system that projects the light modulated by the light modulation element.

15. A projector comprising:

a discharge lamp that emits light,

the discharge lamp driving device according to claim **7**;

a light modulation element that modulates light emitted from the discharge lamp according to a video signal; and

a projection optical system that projects the light modulated by the light modulation element.

16. A projector comprising:

a discharge lamp that emits light,

the discharge lamp driving device according to claim **8**;

a light modulation element that modulates light emitted from the discharge lamp according to a video signal; and

a projection optical system that projects the light modulated by the light modulation element.

17. A method of driving a discharge lamp that is driven by supplying a driving current to the discharge lamp, the method comprising:

supplying the driving current having driving periods to the discharge lamp, the driving period including:

a mixing period which alternately has an AC period in which an alternating current is supplied to the discharge lamp and a first DC period in which a direct current is supplied to the discharge lamp,

a second DC period which is provided immediately after the mixing period and in which a direct current having a polarity which is the same as that of the direct current in the first DC period is supplied to the discharge lamp, and

a third DC period which is provided immediately after the second DC period and in which a direct current having a polarity opposite to that of the direct current in the second DC period is supplied to the discharge lamp,

wherein the length of the second DC period is longer than the length of the first DC period, and

the length of the third DC period is longer than or equal to the length of the first DC period and shorter than the length of the second DC period.

18. The method of driving a discharge lamp according to claim **17**,

wherein the driving current has a plurality of the driving periods, and

the direct currents in the first DC periods of the adjacent driving periods have different polarities from each other.

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